MEMORANDUM

Technology Screening Memorandum to Support Alternatives Development, Impoundments 1 and 2, Operable Unit 8, American Cyanamid Superfund Site, Bridgewater, New Jersey

PREPARED FOR:	Mark Austin/U.S. Environmental Protection Agency
COPY TO:	Michael Sivak/U.S. Environmental Protection Agency Joseph Battipaglia/U.S. Environmental Protection Agency Ed Barth/U.S. Environmental Protection Agency Russ Downey/Pfizer, Inc. Vince D'Aco/Quantum Management Group
PREPARED BY:	CH2M HILL
DATE:	September 9, 2015

This memorandum describes the technology screening process and presents the technologies and process options retained for subsequent development of remedial alternatives as part of the Focused Feasibility Study (FFS) for Impoundments 1 and 2, Operable Unit (OU) 8, at the American Cyanamid Superfund Site in Bridgewater, New Jersey (Site). This memorandum only covers screening of remedial technologies and more specifically the individual process options that fall under those technology categories.

The overall objective of this memorandum is to determine the process options that are retained for subsequent assembly into remedial alternatives. The majority of the process options presented and screened in this memorandum are not standalone options; they will be combined with other process options and engineering controls into full spectrum remedial alternatives that can achieve remedial action objectives (RAOs). The remedial alternatives assembled using the retained process options will then be subject to detailed evaluation and comparative analysis in the FFS report. Technology and process option screening was conducted in accordance with United States Environmental Protection Agency (USEPA) guidance (USEPA 1988).

Background

Impoundments 1 and 2 are approximately 4.5 acres in size (combined) and contain approximately 55,000 cubic yards of acid tar. The impoundment materials are characterized by low pH (typically less than 2 standard units [SU]), and USEPA has identified the volatile organic compound and semivolatile organic compound contents, primarily benzene and naphthalene, as principal threat waste (PTW). The impoundment materials consist of hard crumbly and viscous rubbery tar, as well as some coal aggregate (Impoundment 1 only) and clay/sand/silt material (Impoundment 1 only). Currently, a synthetic cover is on top of each impoundment and a water cap is above the synthetic cover for vapor control.

Impoundments 1 and 2 are located in the South Area of the Site, approximately 700 feet north of the Raritan River and within the floodplain. The impoundments are within the flood hazard area (defined using a 100-year flood equivalent plus a factor of safety) as indicated by the Federal Emergency Management Agency. Residential and commercial properties are located north, east, and northeast of the Site.

540456

Bench-scale (laboratory) treatability studies and a field-scale pilot study have been conducted to help evaluate technologies that might be effective for remediation of Impoundments 1 and 2 (CH2M HILL [CH2M] 2014, 2015). In 2014, a pilot study evaluated the feasibility and efficacy of in-situ solidification/stabilization (ISS), in-situ thermal treatment (ISTT), and a combination of ISTT and ISS (CH2M 2015) to treat the impoundment materials in place.

Part of the FFS process is to develop, screen, and evaluate candidate remedial alternatives for OU8. Overall, the FFS process is intended to identify alternatives that will meet the RAOs and satisfy applicable or relevant and appropriate requirements. The following preliminary RAOs were presented in the Revised Impoundments 1 and 2 FFS Work Plan (CH2M 2012), which USEPA approved on September 13, 2012:

- Remove, treat, or contain material that meets the definition of PTW.
- Prevent current or potential future migration of material that meets the definition of PTW from the Site that would result in direct contact or inhalation exposure.
- Prevent and minimize human and ecological exposure to constituents contained in impoundment materials and within adjacent earthen berms.
- Prevent and minimize sources of groundwater impacts resulting in long-term improvement of groundwater quality and eventual achievement of applicable regulatory criteria.

The RAOs listed above are preliminary and will be finalized during development of the FFS.

It is important to recognize that OU8 represents one OU being remediated at the Site. In addition to other Site areas, sitewide groundwater is being remediated and is addressed as part of OU4. The sitewide groundwater remedy involves extraction and treatment of groundwater, including the capture, extraction, and treatment of groundwater downgradient of Impoundments 1 and 2.

Identification and Screening of Remedial Technologies and Process Options

General response actions (GRAs) are general categories of actions that could be used to satisfy RAOs. The GRAs identified to achieve OU8 RAOs include:

- No Action
- Containment
- Treatment
- Removal
- Disposal

Following USEPA guidance (USEPA 1988), technology types and process options were identified for each GRA, as shown in Table 1A. Because USEPA has identified the materials in OU8 as PTW, treatment of the PTW will be an important aspect of the alternatives to be developed (USEPA 1991). For the "Treatment" GRA, the process options were organized by "in-situ" and "ex-situ" treatment technologies, along with technologies to treat process vapor emissions. The technologies and process options for each GRA were screened using the criteria of effectiveness, implementability, and cost (USEPA 1988), as defined below. In addition, the tenets of sustainability as outlined in the USEPA Clean and Green Policy (http://www.epa.gov/region2/superfund/green_remediation/policy.html) were incorporated into the screening process.

- <u>Effectiveness</u> – Considers the ability to handle the estimated areas or volumes of media and meeting the remediation goals identified in the RAOs; the potential impacts to human health and the environment during the construction and implementation phase; and how proven and reliable the process is with respect to the contaminants and conditions at the site. The scoring used for the relative effectiveness assessment is: Low (1); Low-Moderate (2); Moderate (3); Moderate-High (4); High (5).

- Implementability – Encompasses the technical and administrative feasibility of implementing a technology or process option. This includes the ability to obtain necessary permits for offsite actions, availability of treatment, storage and disposal services (including capacity), and availability of necessary equipment and skilled workers to implement the technology or process option. The scoring used for the relative implementability assessment is: Low (1); Low-Moderate (2); Moderate (3); Moderate-High (4); High (5).
- Cost – Relative capital and operation and maintenance (O&M) cost assessments are made on the basis of engineering judgment; costs are identified as being high, low, or medium relative to other process options in the same technology type. The scoring used for the relative cost assessment is: Low (5); Low-Moderate (4); Moderate (3); Moderate-High (2); High (1).

The screening was conducted to assess the relative performance of a particular process option as compared to other process options within a given technology type. For example, if multiple process options are equally effective, a process option that is more challenging to implement may be screened out. Table 1A identifies the GRAs, technologies, and process options that were screened based on effectiveness, implementability, and cost. Technologies and process options that are not retained are shaded in grey in Table 1A. This table also provides rationale for the decisions regarding whether a process option is retained for development of remedial alternatives or whether it is screened out. Based on the technology screening results, the process options retained for development of remedial alternatives are shown in Table 1B.

The process options passing the technology screening steps for effectiveness, implementability, and cost will be retained and combined with other process options to form the initial list of remedial alternatives for OU8. The initial list of remedial alternatives is expected to be further screened to identify the final list of remedial alternatives that will be retained for detailed analysis in the FFS.

References

CH2M HILL (CH2M). 2012. *Work Plan, Focused Feasibility Study Impoundments 1 and 2. American Cyanamid Superfund Site.* September.

CH2M HILL (CH2M). 2014. *Revised Impoundments 1 and 2 Treatability Study Results. American Cyanamid Superfund Site.* August.

CH2M HILL (CH2M). 2015. *Field-Scale Demonstration Study Results Report for Operable Unit 8 Pilot Study. American Cyanamid Superfund Site.* February 26.

New Jersey Department of Environmental Protection. 1998. Superfund Record of Decision for Group III Impoundments (1, 2, 3, 4, 5, 14, 20 &26). American Cyanamid Site. American Home Products Corporation, Bridgewater Township, Somerset County, New Jersey. October

U.S. Environmental Protection Agency (USEPA). 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.* OSWER Directive 9355.3-01. EPA/540/G-89/004.

U.S. Environmental Protection Agency (USEPA). 1991. *A Guide to Principal Threat and Low Level Threat Wastes.* Superfund Publication 9380.3-06FS.

Tables

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
No Action	No Action	No Action	No additional activities beyond what is currently conducted will be implemented. The following activities will still be conducted: operation of the removal action groundwater collection trench and treatment system, periodic inspections and maintenance of the berms, maintenance of fencing and site security, maintenance of the water cap to suppress emissions, maintenance of berm armoring for flood resistance, maintenance of a geosynthetic cover over the materials for further flood resistance, and periodic ambient air monitoring.	**Low-Moderate (2).** While no activities are planned to treat the principal threat waste, the groundwater pathway to the river is eliminated, preventing exposure.	**Low (1).** While there are no challenging technologies to implement, it is unlikely to be accepted.	**Low (5).**	**Retain.** This option is retained per the FFS process.
Containment	Cap/Cover	Soil Cover	Use of clean soil/fill to create a physical barrier and prevent physical contact with subsurface materials. Surface would be graded and vegetated to promote runoff and help prevent erosion. This technology would likely be applied within a remedial alternative in conjunction with other in-situ treatment technologies.	**Low-Moderate (2).** Can be effective for limiting physical contact with waste materials and limited effectiveness minimizing physical mobility of impacted media; does not prevent infiltration/ leaching. Underlying materials must have adequate strength to support a soil cover. Effective technology when combined with other in-situ remediation technologies; however, it is not expected to reduce the toxicity, mobility, or volume of impacts as a stand-alone remedy.	**High (5).** While impoundment material must be strengthened before a soil cover can be adequately supported, soil cover materials are readily available and easily placed.	**Low (5).** Soil covers are generally inexpensive to design and construct.	**Retain.** This option is retained for assembly with other process options that treat PTW and increase impoundment material compressive strength through treatment operations.
		Low-Permeability Engineered Cover	A multi-layered, low-permeability engineered cover used to prevent physical contact with subsurface materials and prevent infiltration of precipitation. This technology is frequently coupled with subsurface vapor collection systems. This technology would likely be applied within a remedial alternative in conjunction with other in-situ treatment technologies.	**Moderate (3).** Can be effective for limiting contact with wastes and mobility of underlying media; prevents infiltration/leaching. Is not expected to reduce the toxicity or volume of impacts as a stand-alone remedy.	**Moderate-High (4)**. While impoundment material must be strengthened before a low-permeability engineered cover can be adequately supported, cover materials are readily available and easily placed. This receives a lower implementability rating than the soil cover because installation of an impermeable cover is more complicated than installing a simple soil cover.	**Moderate (3).** Low-permeability covers are more expensive to design and construct than soil covers.-Based on the impoundments' location within a floodplain, costs may be higher than a typical low-permeability engineered cover.	**Retain.** This option is retained for assembly with other process options that increase impoundment material compressive strength through treatment operations.
	Groundwater Gradient Control	Hydraulic Barriers	A physical barrier which reduces the lateral migration of groundwater, waste materials (treated or untreated) and if present, nonaqueous phase liquid (NAPL) within Impoundments 1 and 2. Barriers may be constructed using a wide variety of techniques (e.g., sheet piles, soil bentonite slurry walls). This technology would likely be applied within a remedial alternative in conjunction with other in-situ treatment technologies.	**Moderate (3)**. Barriers can be effective for limiting lateral migration of groundwater and site-related contaminants; effectiveness can be increased when site conditions allow barriers to be sealed vertically by anchoring in underlying low-permeability strata. Establishing a vertical seal at the bedrock contact could be difficult, but feasible.	**Moderate (3).** Construction materials and equipment are readily available. Subsurface conditions below the impoundments are composed of gravel overtop of shallow bedrock. These conditions may challenge sheet pile installation or slurry-based trenching. Barrier wall construction may disturb neighboring wetlands.	**Moderate (3)**. Barrier construction costs are influenced by subsurface conditions. The presence of gravel and shallow bedrock may increase total cost to install a barrier suitable for hydraulic containment of Impoundments 1 and 2.	**Retain.** This process option is retained for assembly with other process options that reduce toxicity, mobility, or volume through in-situ treatment.
		Extraction Wells	An imposed barrier, developed by groundwater extraction which can reduce the lateral and vertical migration of groundwater, NAPL, or waste materials away from the boundary of Impoundments 1 and 2. This does not include groundwater extraction associated with OU4 (sitewide groundwater), which already occurs downgradient of OU8. This technology would likely be applied within a remedial alternative in conjunction with other in-situ treatment technologies.	**Moderate (3).** Can be effective for limiting lateral and vertical mobility of groundwater and NAPL from Impoundment 1 and 2. This technology can reduce the toxicity, mobility, and volume of site contaminants by reducing mobility, but it must be coupled with ex-situ treatment operations.	**Moderate (3)**. Groundwater extraction is currently employed downgradient of Impoundments 1 and 2 for recovery of dissolved phase contaminants. However, extraction efforts adjacent to impoundments must be capable of NAPL collection and extraction. Although extraction wells are readily installed and often used for hydraulic control, the collection, removal, conveyance, and treatment of multiple fluid types by this approach presents greater technical challenges over groundwater extraction alone.	**Moderate (3).** Capital installation costs for extraction well installation are low relative to hydraulic barriers like sheet piles or slurry walls. However, O&M costs are higher based on the volume of water or NAPL which must be extracted and the complexity of operations needed for water treatment prior to discharge. The incremental equipment and O&M costs for NAPL removal, treatment, and disposal (if needed) are significant.	**Retain.** This option is retained for assembly with other process options that reduce toxicity, mobility, or volume through in-situ treatment. May be used to address residual NAPL if determined present outside the Impoundment 1 and 2 footprint.

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
Treatment	In-Situ	In-Situ Chemical Oxidation (ISCO)	Subsurface addition of an oxidizing agent to promote abiotic in-situ oxidation of organic compounds. Oxidant can be delivered using fixed injection points or mixed in-situ using augers or equipment designed for soil mixing.	**Low (1).** This technology can be effective for COC treatment in soil and groundwater when adequate oxidant can be supplied and good contact between contaminant and reagent is achieved. The oxidant demand posed by impoundment contents will be extremely high given the nature of impoundment contents and in particular the very high organic content of the acid tar; as such, the mass of reagents needed to impart significant reduction of contaminant toxicity and volume is likely prohibitive for this technology.	**Low-Moderate (2).** Oxidants and mixing equipment are readily available. Oxidant addition to impoundment materials through large-diameter mixers or augers can be readily implemented. Elevated temperatures of reaction are likely; therefore, active recovery and treatment of volatile emissions would be needed during implementation. Impoundment materials lack compressive strength capable of supporting mixing equipment; as such, provisions to increase impoundment material bearing strength or strategies for oxidant delivery over water must also be developed for effective implementation of this technology.	**High (1)**. Extremely large quantities of chemical oxidants will be needed to impart significant reduction of contaminant toxicity and volume given the presence of highly concentrated waste material within Impoundments 1 and 2. In addition, the presence of the water cap and absence of material, which can support mixing equipment, will significantly increase implementation costs for this technology.	**Discard.** Elevated high organic content requires an extremely high oxidant demand and consequently the effectiveness and implementability of this technology for treatment of acid tar in the impoundments is questionable.
		Vapor Extraction	Vapor extraction is a physical removal technology that uses a vacuum system to remove vapors from the subsurface. This technology is frequently coupled with vapor treatment processes that are applicable for site-related COCs prior to atmospheric discharge. Can be used to control vapor emissions during implementation of other technologies; may also be used more passively after ISS or other technology. This technology would likely be applied within a remedial alternative in conjunction with other technologies, such as ISS.	**Moderate (3).** Physical and chemical characteristics of the constituents in the impoundment materials will influence the effectiveness of this technology. Permeability of the materials is required to facilitate vapor flow through the materials to be treated. The integration of supplemental processes to improve mass transfer of volatile components such as mixing, heating, or permeability enhancements can significantly enhance technology efficacy and ability to reduce toxicity and volume of materials contained within Impoundments 1 and 2. May be effectively combined with other process options as part of an alternative.	**Moderate (3).** Vapor extraction is a full-scale technology and is commercially available. This process may be implementable as a secondary treatment process, after initial treatment using other methods to improve material strength, neutralize pH, and increase permeability characteristics. Treatment processes for extracted vapors would be required to protect workers and the community in the near term.	**Low (5).** Overall costs for vapor extraction may be low when combined with other active in-situ technologies. Offgas treatment is expected to be the primary cost driver.	**Retain.** This option is capable of reducing toxicity and volume of COCs contained within the impoundments. Vapor extraction is retained for assembly with other technologies, which can enhance contaminant removal, reduce future mobility, and prevent direct contact with impoundment contents.
		Air Sparging	Air is injected into the impoundment material to remove compounds of concern through volatilization and air stripping. May also be used at lower airflow rates to promote biodegradation. Often coupled with vapor extraction for collection and treatment of displaced VOCs at higher flow rates. Can be implemented via injection wells, during ISS, or after ISS or other pretreatment.	**Low (1).** This technology can be very effective when sufficient permeability is present for injected air to contact COCs that reside within a water saturated solid matrix. Overall, permeability of the tar contained within the impoundments is very low; although some of the impoundment material is porous, the majority lack the requisite physical characteristics needed to impart efficient removal of COCs.	**Moderate (3).** Numerous full-scale operations have been implemented to treat groundwater and soil contaminated by VOCs using vertically or horizontally drilled wells. May be implementable as a secondary treatment process, after initial treatment using other methods to improve material strength, neutralize pH, and increase permeability characteristics. Treatment processes for extracted vapors would be required to protect workers and the community in the near term.	**Low (5).** Overall costs for air sparging are low when compared to other active in-situ technologies. Offgas treatment is expected to be the primary cost driver.	**Discard**. As a stand-alone technology, air sparging is not expected to be as effective as other approaches for physical removal of COCs. Similarly, in a combined approach, other technologies will be more effective in reducing the toxicity and volume of COCs present in the impoundment materials.
		In-Situ Bioremediation (ISB)	For non-chlorinated VOCs, electron acceptors (e.g., oxygen, nitrate, sulfate) are added via injection wells to support microbial activity that degrades the COCs. The COCs are used as an electron donor (a food source) to support metabolic activity.	**Low (1).** While benzene and other VOCs in groundwater have been successfully remediated via ISB, it is not expected that acid tars would be successfully remediated. Successful bioremediation requires a more moderate pH range (e.g., 5 to 8 SU). In addition, the COCs must be in an aqueous phase to be accessible to microbes. Effective transfer of electron acceptor is also required. Air sparing is typically the most cost-effective approach of electron acceptor delivery, and its effectiveness is limited, as discussed above.	**Low (1).** ISB typically is easily implemented; however, with the acidic conditions and tar material, implementation would be very challenging.	**High (1).** ISB is often a lower-cost in-situ process option. However, due to the challenges associated with the physical nature of the impoundment materials, it would be expensive to make ISB an effective option.	**Discard.** ISB is discarded because of its ineffectiveness and implementability challenges relative to other in-situ process options.

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
Treatment (continued)	In-Situ (continued)	In-Situ Stabilization/ Solidification (ISS)	Target contaminants are physically bound or encapsulated within a stabilized mass (solidification). A wide variety of technical strategies can be applied for ISS, which may incorporate large-diameter mixers and augers or specialty designed equipment for reagent blending with impoundment materials. The blending process can also be applied for homogenization and neutralization of impoundment materials through addition of alkaline reagents to buffer the material. This technology would likely be applied within a remedial alternative in conjunction with other technologies, such as implementation of an engineered cover and subsurface hydraulic barrier.	**Moderate-High (4).** The OU8 pilot test demonstrated that ISS can reduce the VOC mass by approximately 25 percent, reduce the physical mobility of tar materials, and reduce the leachability of COCs, specifically benzene and naphthalene, by more than 90 percent. The treated material possessed high compressive strength. ISS also was effective in neutralization of acidity. The total volume of material increased due to the addition of pozzolanic reagents.	**Moderate-High (4).** Overall implementability of ISS for treatment of impoundment material is moderate to high. There are numerous vendors and equipment capable of reagent addition. Amendments (e.g., neutralization agents and pozzolans) to achieve desired properties are readily available. As demonstrated during the pilot testing, ISS operations are expected to increase material temperature, which enhances VOC removal during mixing. Vapors must be captured and treated prior to discharge. Air monitoring is required to ensure protection of workers and the community during implementation.	**Moderate-High (2).** Stabilization costs are moderate when compared to other technologies. The costs are driven primarily by equipment and labor; bench-scale testing can be performed to optimize reagent addition and reduce amendment costs. Treatment of Impoundments 1 and 2 will require collection and treatment of vapors.	**Retain.** This option is capable of reducing toxicity and mobility of COCs contained within the impoundments. Optimization of the stabilization reagents is recommended during design to mitigate volume expansion if this process option is utilized. Optimization will also be required if ISS is used as a pretreatment process for ISTT. This option will be combined with other options to form remedial alternatives.
		In-Situ Thermal Treatment (ISTT)	Uses heat to enhance volatilization of VOCs/SVOCs. Heat is applied via thermal conduction, resistive heating, or through other methods using electrodes or heaters placed in the treatment zone. The type of heating used (e.g., resistive, conductive,) depends on the physical characteristics of materials being treated. Fluids (vapor and liquids) are collected from the treatment zone using multiphase extraction wells (MPE) and treated prior to discharge. Pretreatment, e.g. ISS, is required to neutralize acidity and provide strength. Note for this evaluation, steam heating is discussed separately. This technology would likely be applied within a remedial alternative in conjunction with other technologies, such as ISS.	**High (5).** Heating was demonstrated to be effective for removal of VOCs (greater than 90 percent benzene removal) during the 2014 pilot study. In addition, leaching was demonstrated to be reduced by greater than 90 percent. Corrosion of heaters in the pilot study resulted in inconsistent heating and treatment. Additional treatment (e.g., neutralization) was required following heating in the pilot study to neutralize residual acidity in the acid tars to make them non-corrosive.	**Moderate (2).** Numerous full-scale operations have been implemented for VOC removal; however, none has treated acid tar. Several commercial providers of this technology are available. The low pH of impoundment material presents a significant challenge to heating operations as corrosion processes are strongly accelerated at increased temperature. Fluid extraction and treatment concurrent with heating system operation is a technology requisite; air monitoring is required to ensure protection of workers and the community during implementation. There are safety challenges and concerns associated with operating ISTT in a floodplain over an extended period because of the presence of hot tars and high VOC vapor concentrations. In addition, the equipment could not be demobilized safely/quickly in the event of a flood.	**High (1).** ISTT will require the greatest construction and operating costs relative to other in-situ process options. In addition to the high cost of constructing and operating the thermal treatment system, the need for pretreatment and high efficiency vapor treatment further increase the cost associated with this technology.	**Retain.** Field demonstrated technology in the reduction of COCs present within the impoundment material. Based on lessons learned during the 2014 pilot study, ISTT would be performed only after ISS/neutralization to help minimize heater corrosion and address technical feasibility concerns for impoundment vapor cover construction during heating. This process option will be combined with other treatment and engineering control options to form remedial alternatives.
		Steam-Enhanced COC Removal	Steam and compressed air are introduced into the impoundment materials through injection points (wells or augers). Heating of the impoundment materials enhances volatilization and stripping of COCs. Fluids recovered are removed via MPE and collected for aboveground treatment and destruction. This technology would likely be applied within a remedial alternative in conjunction with other technologies, such as ISS. May be combined with an engineered cover and subsurface hydraulic barrier or possibly excavation and disposal.	**Moderate (3).** Can be an effective technology for treatment of VOCs in high concentration source areas where adequate contact between the VOCs and steam is achieved. Construction materials must be resistant to acidic conditions and high VOC concentrations. Would need to be combined with other technologies to neutralize acidity and achieve the required contact.	**Moderate (3)**. Shallow depth, specifically the absence of overburden pressure, make it challenging to effectively distribute steam; similarly, low permeability of the impoundment material will limit radial influence of injection points. Delivery using augers, as supplied for stabilization operations, would increase overall implementability for heating impoundment materials during mixing. A steam generation plant and vapor-liquid treatment and NAPL recovery systems would be necessary. Like other in-situ technologies, significant offgas treatment will be required.	**Moderate-High (2).** As a standalone technology, steam injection costs are projected to be similar to ISTT costs. However, when considered as a process to enhance stabilization, equipment to implement steam injection is projected to impart only minor cost escalation to stabilization efforts. Costs are largely dependent on system size, energy cost, mass of steam injected to impart desired treatment results, and production rates.	**Retain.** This option can potentially reduce concentrations of VOCs in the waste materials and render materials more amenable to supplemental treatment processes or removal. Limited SVOC treatment within the waste materials may occur. Bench-scale laboratory testing may be required. This option will be retained and combined with other process options to form remedial alternatives.
		Freezing	Impoundment materials are cooled to the point they become solid (frozen); solidified materials are directly excavated and transported to a facility for ex-situ treatment and disposal.	**Low (1).** Freezing the impoundment materials would limit the production of VOC and odor emissions during excavation; however, the approach requires adding supplemental treatment to reduce COC mass. Overall, freezing would produce a material that is more solid than the raw impoundment materials; but even in a chilled state, the potential for high vapor phase emissions will exist.	**Low (1).** This technology likely would be difficult to implement because of the challenge of removing enough heat to solidify the impoundment materials. The potential for freezing of the acid tar is unknown, and with few commercial providers, overall implementability of this technology is considered low.	**High (1)**. Infrastructure and resources to implement this alternative would be high. Strategies to implement in the presence of the existing water cap would further add logistical complexity and overall cost.	**Discard.** This option is untested for the proposed application and is impractical to implement. In addition, it would require cold storage facilities to await ex-situ treatment or refrigerated transport to offsite facilities, which would add further to logistical complexity and overall cost.

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
Treatment (continued)	In-Situ (continued)	Surfactant/Co-solvent Flushing (Soil Flushing)	In-situ delivery of chemical reagents including water, surfactants, co-solvents, or other facilitators to enhance the physical displacement, solubilization, or desorption of target contaminants. Mobilized contaminants in the flushing solution are extracted and treated.	**Low (1).** Not demonstrated to be a viable technology for the impoundment materials because of the high VOC content and immiscible properties exhibited by the tar fraction contained in within Impoundment 1 and 2.	**Low (1)**. Soil flushing is a technology that has had limited use in site remediation. The availability of qualified contractors capable of implementing the technology is very limited, and extensive laboratory testing would be needed to confirm efficacy and selection of appropriate reagents to solubilize site COCs.	**High (1).** This option is projected to have high capital and operations costs. The site-specific aspects of application necessitates extensive pre-design data collection and treatability studies. Full-scale operation requires the management of multiple chemicals, treatment of multi-component fluid streams and disposal of complex aqueous phase waste mixtures.	**Discard.** This option is untested for the proposed application and is believed to be impractical to implement. Process option has not been demonstrated for impoundment materials.
	Ex-Situ	Bioremediation	Use of land farming, composting, or slurry bioreactors to treat material removed from the impoundments. Aerobic processes would be used for the COCs of interest (e.g., benzene and naphthalene). Neutralization would be required, as well as significant dilution or conditioning to make the material suitable for biodegradation to occur.	**Low (1).** While bioremediation of benzene is a demonstrated technology/process option, the effectiveness of bioremediation for the impoundment materials is projected to be low based on extremely high COC concentration and the characteristics of excavated materials (e.g., nonaqueous nature, tackiness, and the presence of salts). In addition, bioremediation technologies are most effective when the pH range is 5 to 8 SU.	**Low (1).** Not easily implemented at the site because of the high concentrations of VOCs, physical nature of the materials and low pH, as bioremediation technologies are most effective when the pH range is 5 to 8 SU. In addition, excavation and land farming of untreated impoundment materials is not recommended due to the high VOC concentrations and potential for unacceptable exposures to site workers or the surrounding community.	**Moderate-High (2).** This option is projected to have high capital and operations costs. The site-specific aspects of application necessitates extensive pre-design data collection and treatability studies. Full-scale operation requires the management of multiple chemicals, treatment of multi-component fluid streams to maintain biological activity.	**Discard.** This option is untested for the proposed application and is impractical to implement. Process option has not been demonstrated for the impoundment materials. Elevated concentration of VOCs, SVOCs, and very low pH in the waste materials will be toxic to microbes.
		Co-Burning Cement Kiln	Impoundment materials are excavated, transported, blended and fed to a cement kiln as fuel. The cement kiln operates at 2,500 to 2,900 °F, and organic compounds are destroyed at these temperatures.	**Moderate-High (4).** The heat of a cement kiln would destroy the organic content of the impoundment materials, and the cement kiln dust would neutralize the acidic portion of the wastes. The residual waste materials become incorporated into the cement mixture. The acceptance of solids for use at the cement kiln may be limited by the presence of acid volatile sulfides in the impoundment materials, so not all treated tar materials are acceptable for cement kiln co-burning.	**Moderate (3).** The use of cement kilns to treat waste materials is well documented. Cement kilns maintain Resource Conservation and Recovery Act (RCRA) and Clean Air Act permits. Impoundment material would need to be treated in-situ before shipping to the cement kiln for treatment (so the materials can be removed without emissions issues). ISTT-treated material from the 2014 pilot study was subsequently treated at the Green America cement kiln in Hannibal, Missouri. ISS-only treated materials from the pilot study could not be accepted at this facility because of elevated acid volatile sulfide levels. The acceptance throughput rate of impoundment materials by kiln may control removal rate and project timeline. May be viable secondary treatment after initial in-situ treatment.	**Moderate-High (2).** Treatment costs for cement kiln co-burning are higher than some ex-situ process options and lower than other options.	**Retain.** This option may be applicable for treatment of material after removal from the impoundments or for residuals produced through other treatment processes performed onsite. It will be retained and combined with other process options to form remedial alternatives.
		Hazardous Waste Incineration	Excavated impoundment materials or treatment residuals are excavated and treated in an onsite incinerator, or transported offsite and fed directly to a permitted hazardous waste incinerator. The high temperature combustion destroys the organic content of the wastes, and the sulfur compounds are liberated as sulfur gases, which are removed by scrubbing processes. If onsite incineration were used, subsequent disposal would be required.	**High (5).** The heat of the incinerator would destroy the organic content of the impoundment materials. Treatment would reduce the volume of impoundment material, but management and disposal of combustion ash is still required.	**Moderate (3).** The use of incinerators to treat waste materials is well documented; qualified facilities are regulated by RCRA and Clean Air Act permits. Implementation of onsite incineration would require a significant approval process. Impoundment material may need to be treated before excavation for incineration. Acceptance rate of impoundment materials and offsite facilities may control removal rate and project timeline. Throughput rates per facility for offsite incineration are approximately an order of magnitude higher than those for cement kilns. ISS-treated materials from the 2014 pilot study were sent to the Heritage hazardous waste incinerator for final treatment.	**High (1)**. Costs for treatment by incineration are high. This option also requires disposal of residuals after incineration, which would be handled by the hazardous waste incineration facility if treatment were performed offsite.	**Retain.** This option may be applicable for treatment of material after removal from the impoundments or for residuals produced through other treatment processes performed onsite. Because of the anticipated regulatory and public constraints, only offsite (not onsite), incineration is being retained for further consideration. This option will be retained and combined with other process options to form remedial alternatives.

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
Treatment (continued)	Ex-Situ (continued)	Thermal Desorption	Thermal desorbers treat waste by heating the materials in a rotating drum (or other types of reactors) in an oxygen-deficient atmosphere. Typically, treatment is performed onsite. Vapors produced are treated and in some applications can be processed into usable fuel.	**Moderate (3).** Heat from the thermal desorption units rapidly drive off VOCs and SVOCs present within the impoundment material. Treatment will reduce the overall volume of material and produce friable solid materials with limited compressive strength. Heating is projected to have limited effect on pH neutralization, and supplemental neutralization and stabilization may be needed to fulfill landfill requirements. Previous testing on raw impoundment materials at the site showed that land disposal restriction (LDR) concentrations could not be achieved (New Jersey Department of Environmental Protection 1998).[3]	**Moderate (3).** The use of thermal desorption to treat waste materials is well documented. Throughput (desorbed residence time) for desired impoundment material treatment may control removal rate and project timeline. Significant air treatment and permitting is required for these systems, which limits the effectiveness and implementability for full-scale use.	**Moderate-High (2).** Treatment costs for thermal desorption are higher than some ex-situ process options and lower than options. Disposal of the treatment residuals will still be required.	**Discard.** Once material is removed from the impoundments, the preference would be to place material in the CAMU or if additional treatment is required, to send material offsite to minimize potential exposure during treatment. Therefore, other ex-situ treatment options are retained rather than thermal desorption.
		Asphalt Recycling	Excavated impoundment materials or treatment residuals are transported offsite and fed directly to the asphalt mix during the manufacturing process. The materials can be added to either a hot-mix or cold-mix asphalt process.	**Low-Moderate (2).** Some VOC reduction is likely and SVOCs would be integrated into the asphalt matrix.	**Low (1).** Implementability challenges are likely associated with approval to use characteristically hazardous waste in asphalt recycling.	**Moderate-High (2).** Costs are likely comparable to using a cement kiln.	**Discard.** This option is not a proven technology for impoundment materials; additionally, the high VOC content may limit reuse of material after treatment.
	Emissions Treatment	Granular Activated Carbon (GAC)	Vapor generated from material treatment or handling is captured and adsorbed on vapor phase GAC beds to remove VOCs. This method can also be used to treat liquid streams if condensate is generated by the selected treatment option(s).	**Moderate (3)**. The use of GAC to remove VOCs from air and water is well documented with numerous studies and full-scale treatment operations. Not an effective technology for initial treatment of air emissions during ISS or ISTT because of the high VOC and SVOC content expected during treatment. May be more effective technology as secondary treatment processes, after VOC content has been reduced or as part of a passive venting system.	**High (5).** This technology could be readily implemented at the site for low concentration vapor streams, as there are numerous suppliers of equipment and GAC services. This technology is not feasible for very high concentration vapor streams because of safety concerns, specifically the potential for vapor phase carbon bed fires.	**Moderate (3); High (1).** When applied for low concentration vapor streams, this technology is cost effective. However, application of GAC for highly concentrated, high volume treatment is inefficient and costly because of excessive GAC consumption and increased O&M requirements. The moderate cost rating is applicable for use on low concentration vapor streams.	**Retain.** Treatment of high concentration vapor streams with GAC is not feasible because of safety concerns. Use of the technology will be considered for treatment of low concentration, low volume vapor streams where alternative technologies are not considered feasible. This option will be combined with other process options to form remedial alternatives.
		Thermal Oxidizer	Vapor generated from material treatment or handling is heated and destroyed by thermal oxidation in a controlled combustion chamber. The carbon from the VOCs is bound to oxygen and released as carbon dioxide; acid gasses and sulfur-bearing compounds generated during combustion processes are removed from oxidizer exhaust by caustic scrubbing.	**High (5).** Thermal oxidizer offgas treatment is a proven technology; the concepts, theory, and engineering aspects of the technology are well developed. Pilot testing completed onsite demonstrated the ability to effectively handle sulfur and acidic exhaust gasses using a caustic scrubber.	**High (5).** There are multiple suppliers of thermal oxidizers capable of treating vapor phase emissions generated during handling or treatment of impoundment materials. As with all air treatment technologies, emission control and air permitting will be required. A thermal oxidizer was used during the 2014 pilot study and effectively treated vapors generated via ISS and ISTT.	**Moderate-High (2).** Capital costs are higher when compared to other air treatment technologies. However, given the mas of VOCs present operations life-cycle cost of the oxidizer compared to alternate approaches like carbon adsorption is projected to be lower.	**Retain.** This option is projected to be the most effective approach for the treatment of high concentration, high volume vapor streams generated during treatment or handling of impoundment materials. This option will be combined with other process options to form remedial alternatives.
		Catalytic Oxidizer	Vapor generated from material treatment or handling is heated and destroyed in the presence of a catalyst. The oxidation occurs through a chemical reaction between the VOC hydrocarbon molecules and a precious-metal catalyst bed that is internal to the oxidizer system. The catalyst accelerates the rate of a chemical reaction, allowing the oxidation and VOC destruction to occur at a lower temperature range (typically 550 to 650 °F).	**Low (2).** Catalytic thermal oxidation is a developed, refined, and proven technology for VOC destruction; the concepts, theory, and engineering aspects of the technology are well documented. However, the precious metal catalyst are easily poisoned by sulfur-bearing compounds. Once deactivated by sulfur, catalyst bed replacement is needed, which is very costly.	**High (5).** There are multiple suppliers of catalytic oxidizers capable of treating vapor phase emissions generated during handling or treatment of impoundment materials. However, the presence of sulfur compounds prohibits the use of this treatment technology.	**High (1)**. Sulfur is present in the impoundment materials at appreciable concentration. As a selective and irreversible poison for the platinum-based catalysts used in these systems, application of this option could result in extraordinary operations costs for vapor treatment by this option.	**Discard.** This option is incompatible with process vapor conditions anticipated during treatment or handling of impoundment materials.

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
Removal	Hydraulic Removal	Hydraulic Dredging	Removal of impoundment material as a liquid slurry suspended by mixing with water. The slurry suspension is subsequently conveyed to a dewatering system, where solids are separated from the liquid. The slurry is moved through piping from the excavation area to treatment area using potential created by turning an enclosed auger.	**Moderate (3).** Hydraulic dredging is effective at removing large volumes of sediment and can be implemented without removing the water cap from the impoundments.	**Moderate (3).** Dredging of material is considered implementable using a number of approaches. Dewatering of liquid slurry, however, is considerably more difficult given the VOC content of the material and the high liquid to solid ratio stream that must be managed. The approach will require extensive dewatering facilities with active vapor control. Dewatered material must be subsequently treated before offsite disposal or onsite consolidation in the CAMU.	**High (1).** Equipment and operating costs for this method of removal are projected to be high given vapor control requirements and multiple handling steps needed to produce material suitable for supplemental treatment or disposal.	**Discard.** This option may be moderately effective at removing impoundment materials prior to ex-situ treatment. However, the cost and complexity of treating the process streams generated by this option would be very high and require multiple material handling steps that increase the potential for unacceptable exposures for site workers and surrounding communities.
		Heat and Pump	Removal of impoundment material as a liquid slurry produced following heating with a noncontact heat exchanger placed directly in the impoundments. Through circulation of hot heat transfer fluids to the exchanger, a portion of the impoundment materials will liquefy. The resulting liquid is pumped directly from the impoundments and conveyed to a secondary treatment area for recovery and further processing.	**Low (2).** Effectiveness is predicated on viscosity reduction of the impoundment materials following heating. If the viscosity of the impoundment materials can be lowered, pumping could be effective at removing large volumes of materials without water cap removal. Material heating would increase vapor emissions even higher than those seen with just ambient removal methods. The approach has not been demonstrated onsite and would require extensive testing to fully evaluate potential efficacy onsite.	**Moderate (3).** Thermally enhanced removal of petroleum-derived sludges is a demonstrated technology and commercial suppliers are available to implement this option. However, it is unknown if physical and chemical properties of the impoundment materials can be pumped after heating. In addition, pumping materials through a pipeline may be difficult; heat loss from the pipeline may cause increase viscosity and pipes to clog. Relocation of the heat exchangers and pump head will be required as the materials are removed.	**High (1).** Equipment and operating cost for this method of removal are projected to be high given vapor control requirements and multiple handling steps needed to produce material suitable for supplemental treatment or disposal.	**Discard.** Other removal options provide a better combination of effectiveness and implementability.
		Liquefaction	Use of a diluent (e.g., fuel oil) to help dissolve tar materials in place, followed by pumping of the liquid slurry. The liquid is pumped directly from the impoundments and conveyed to a secondary treatment area for diluent recovery and further processing/treatment.	**Low (2).** Effectiveness is predicated on viscosity reduction of the impoundment materials following diluent additional and mixing. If the viscosity of the impoundment materials can be lowered, pumping could be effective at removing the impoundment material as a liquid. Removal of the water cap is needed for this approach; provisions for the containment collection and destruction of organic vapors is necessary. The approach has not been demonstrated onsite and would require extensive testing to fully evaluate potential efficacy onsite.	**Low (2).** The use of diluents to liquefy and recover acid tar from an open surface impoundment has not been demonstrated; similarly, the availability of services and equipment to implement this approach is limited.	**High (1).** Equipment and operating costs for this method of removal are projected to be high given vapor control requirements and multiple handling steps needed to produce material suitable for supplemental treatment or disposal.	**Discard.** Other removal options provide a better combination of effectiveness and implementability.
	Mechanical Removal	Excavation	Excavation of impoundment materials using a trackhoe, crane, bucket excavator, or similar equipment. Excavated materials are dewatered and placed in a container for storage, transport, treatment, or disposal. To protect workers and the community from exposure to high VOC vapor concentrations, in-situ treatment will be required prior to excavation. Alternatively, it may be possible to excavate untreated acid tar at low production rates using active vapor control measures (e.g. foam) to reduce emissions to acceptable levels.	**Moderate (3).** Mechanical excavation is effective for removing materials from the impoundments. Depending on the alternative/approach, the water cap may be maintained, and water management may be required. Because of the potential for elevated VOC concentrations, air monitoring will be required during excavation. In addition, some pretreatment will be required to address material handling challenges (viscous tars, low pH) and to remove VOCs.	**Moderate (3).** Equipment is readily available for mechanical excavation. However, conventional strategies to control vapor phase emissions during removal at typical production rates are impracticable. Effective control of vapor phase emissions during the excavation and protection of site workers and surrounding community residents remains the primary technical limitation to implementation of this option.	**Moderate (3).** Equipment and operating cost for this method of removal are projected to be high given vapor control requirements and multiple handling steps needed to produce material suitable for supplemental treatment or disposal. Controlling emissions by minimizing production rates will also result in higher costs.	**Retain**. This option is retained for potential application and will be combined with process options that involve treatment and disposal.
Disposal	Onsite	Closure in Place	Following completion of an in-situ treatment, alternative residuals would be capped, the treated area reinforced to withstand floods, and permanently closed in place.	**Moderate-High (4).** When coupled with an appropriate treatment alternative capable of reducing toxicity and mobility of impoundment materials in place closure is considered an effective remedial approach. An effective closure in place can be engineered in the floodplain.	**Moderate-High (4).** In-place closure is implementable. Design and construction provisions to permanently encapsulate treated materials are readily available. A closure in place strategy precludes the exposure potential associated with excavation, ex-situ treatment, and transportation/disposal.	**Moderate-High (2).** Cost of in-place closure is predicated on the individual costs of elements applied for in-situ treatment and capping.	**Retain**. This disposal option is retained for further consideration when combined with in-situ treatment process options. In-situ treatment and capping when properly selected and performed can achieve the remedial action objectives proposed for Impoundments 1 and 2.

Table 1A. Technology and Process Option Screening

General Response Action	Remedial Technology	Process Option	Description	Effectiveness[1]	Implementability[1]	Cost[2]	Retain for Alternative Development?
Disposal (continued)	Onsite (continued)	Impoundment 8 Facility Corrective Action Management Unit (CAMU)	Following completion of an in-situ treatment alternative, residuals would be excavated and transported to the onsite CAMU for final disposition.	**High (5).** When coupled with an appropriate treatment alternative capable of reducing toxicity of impoundment materials, onsite disposal in the CAMU is considered an effective remedial approach. This process option receives a slightly higher score than Closure in Place option because the materials are physically removed from the floodplain.	**Moderate (3).** Excavation following in-situ treatment is implementable. The Impoundment 8 Facility CAMU was designed and purposed for placement of treated residuals from the site. While LDR or TCLP concentrations do not apply to materials placed in the CAMU, concentrations must be such that excavation/ disposal in the CAMU does not create an exposure hazard. Production rate of excavation, supplemental treatment (if needed), and spreading at the CAMU may be limited, which would extend the project duration.	**High (1)**. Cost for CAMU disposal following in-situ treatment are projected to be high given the level of VOC removal needed for safe excavation of the treated residuals.	**Retain.** This disposal option will be retained for analysis with treatment alternatives that can appreciably reduce impoundment material toxicity (e.g., total VOC content).
	Offsite	Nonhazardous Waste Landfill	Following completion of an in-situ treatment alternative, residuals would be excavated and transported offsite to a nonhazardous landfill for final disposition. TCLP concentrations must be met.	**Low (1).** Based on bench and pilot tests conducted to date, remedial technologies have not consistently achieved TCLP concentrations that would allow for nonhazardous disposal.	**Low (1).** Achieving the required treatment standards for offsite disposal in Subtitle C landfill with a nonhazardous classification is unlikely.	**High (1)**. The cost and technical feasibility to achieve treatment levels suitable for nonhazardous disposal are unknown and projected to be prohibitively high.	**Discard**. This disposal option lacks technical feasibility; the type and cost of process options needed to achieve nonhazardous disposal requirements renders the option impractical to implement.
		Hazardous Waste Landfill	Following completion of an in-situ treatment alternative, residuals would be excavated and transported offsite to a hazardous waste landfill for final disposition. LDR concentrations must be met.	**Low (1).** Based on bench and pilot tests conducted to date, remedial technologies have not achieved LDR concentrations.	**Low (1).** Achieving the required treatment standards for offsite disposal in a hazardous waste landfill would present significant technical challenges for all treatment strategies contemplated.	**High (1)**. The cost and technical feasibility to achieve treatment levels suitable for hazardous landfill disposal are unknown and projected to be high.	**Discard.** This disposal option lacks technical feasibility; the type and cost of process options needed to achieve LDRs (required for hazardous waste disposal) renders this option impractical to implement.

Notes:

1. Screening scores for Effectiveness and Implementability are as follows:

   Low: 1 (worst)
   Low-Moderate: 2
   Moderate: 3
   Moderate-High: 4
   High: 5 (best)

2. Screening scores for Cost are as follows:

   Low Cost: 5 (best)
   Low-Moderate Cost: 4
   Moderate Cost: 3
   Moderate-High Cost: 2
   High Cost: 1 (worst)

3. LDRs are not expected to be achieved for any of the process options evaluated.

CAMU – Corrective Action Management Unit
FFS – Focused Feasibility Study
ISB – in-situ bioremediation
ISS – In-Situ Stabilization/Solidification
LDR – land disposal restriction
NAPL – nonaqueous phase liquid
OU – Operable Unit
SU – standard unit
VOC – volatile organic compound
COC – contaminant of concern
GAC – granular activated carbon
ISCO – in-situ chemical oxidation
ISTT – In-Situ Thermal Treatment
MPE – multi-phase extraction
O&M – operation and maintenance
RCRA – Resource Conservation and Recovery Act
SVOC – semivolatile organic compound

Table 1B. Summary of Retained Process Options

General Response Action	Technology	Retained Process Option
No Action	No Action	No Action
Containment	Capping	Soil Cover
		Engineered Cover
	Groundwater Gradient Control	Hydraulic Barriers
		Extraction Wells
Treatment[1]	In-Situ Treatment	Vapor Extraction
		ISS
		ISTT
		Steam-enhanced COC Removal
	Ex-Situ Treatment	Offsite Co-burning Cement Kiln
		Offsite Hazardous Waste Incineration
	Process vapor treatment	Granular Activated Carbon
		Thermal Oxidation
Removal	Mechanical Removal	Excavation
Disposal[1]	Onsite Disposal	Closure In Place
		Corrective Action Management Unit (CAMU)

Notes:
1. Ex-situ treatment options retained following screening will produce residuals which would be disposed offsite. However, since retained ex-situ treatment options incorporate residuals directly into a product for beneficial reuse (cement kiln) and incineration processes already include provisions for ash management, these technologies were evaluated as treatment technologies rather than disposal technologies.